Remote Sensing of Cloud Droplet Number Concentrations

A piece of the puzzle towards understanding aerosol-cloud interactions

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GISS Lunch Seminar

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Introduction

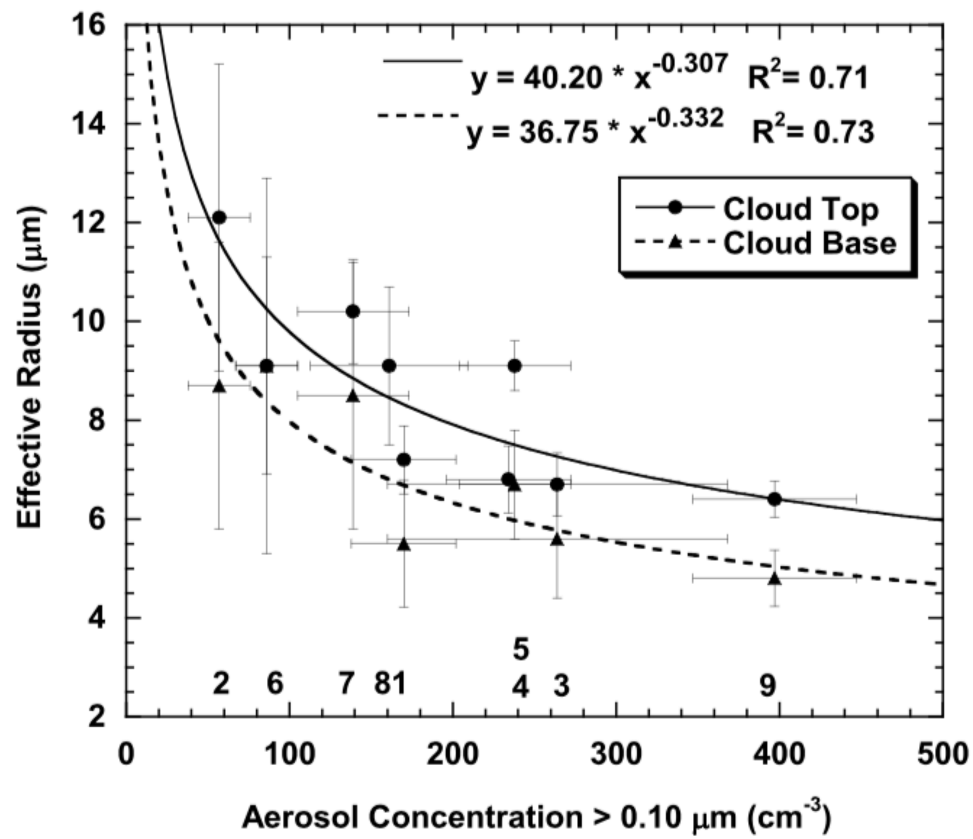
Will focus on:

- Technique the Research Scanning Polarimeter (RSP) uses to retrieve Cloud Droplet Number Concentration (CDNC)
- Comparison with the Cloud Droplet Probe
- 1st deployment of the North Atlantic and Marine Ecosystems Study (NAAMES)

Motivation

Aerosol-cloud interactions

- Twomey [1974] recognized the connection between increasing aerosol particle number concentration and
  - (1) decreasing droplet size
  - (2) increasing cloud droplet number concentration
  - (3) increasing cloud reflectance
- Results in changes to the radiative properties of clouds
- Also impacts cloud evolution, precipitation, local and global climate
- Clouds have the potential to cause significant climate feedbacks



Twohy et al. (2005)

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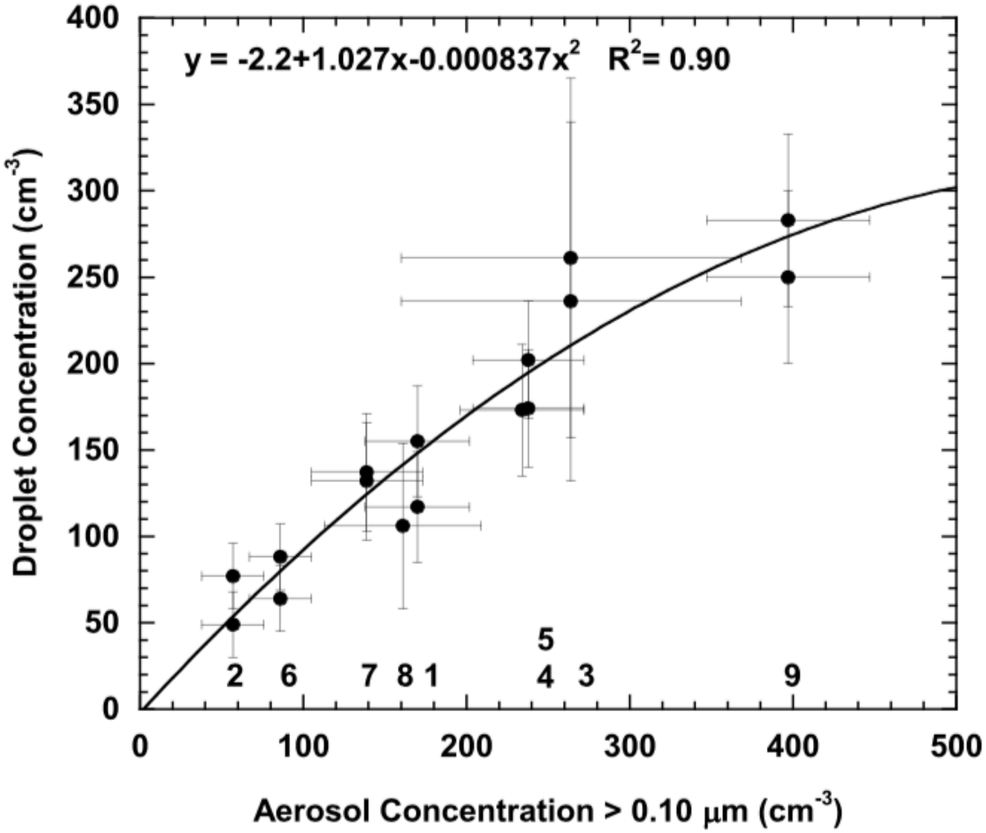
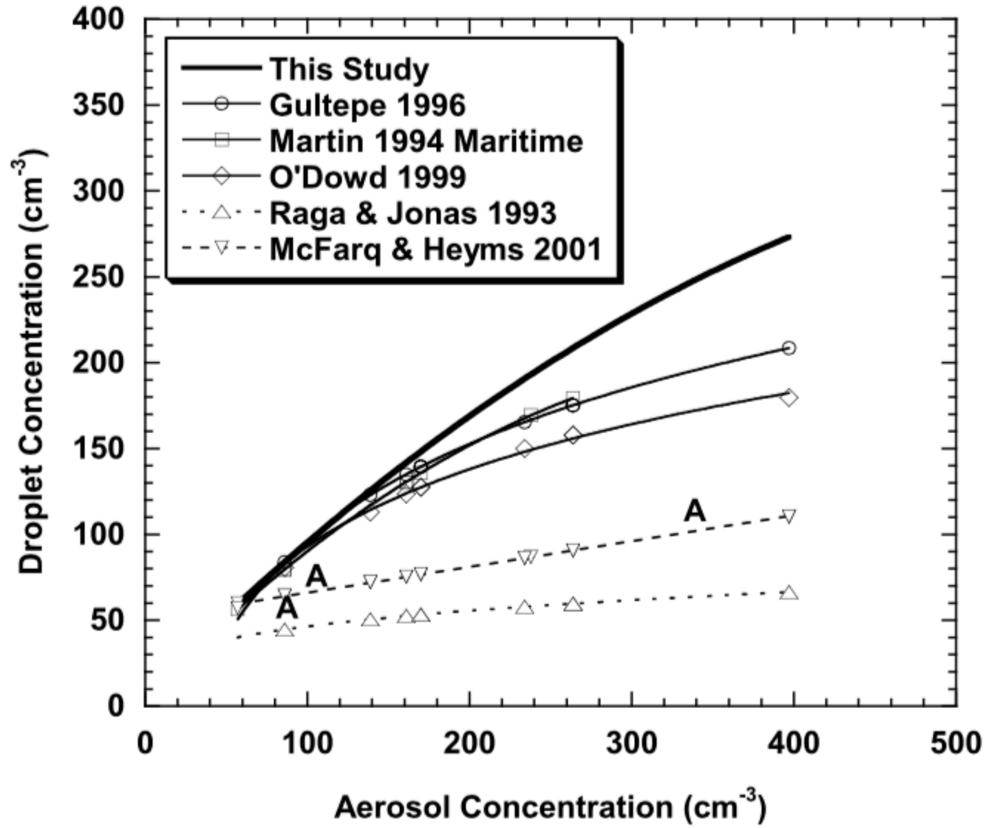


Twohy et al. (2005)

Motivation

Aerosol-cloud interactions

- Aerosol-cloud interactions, or the first indirect effect, can be partially observed through monitoring CDNC
- It is a key parameter that couples surface aerosol composition and chemistry on the one hand and cloud reflectivity on the other



Twohy et al. (2005)

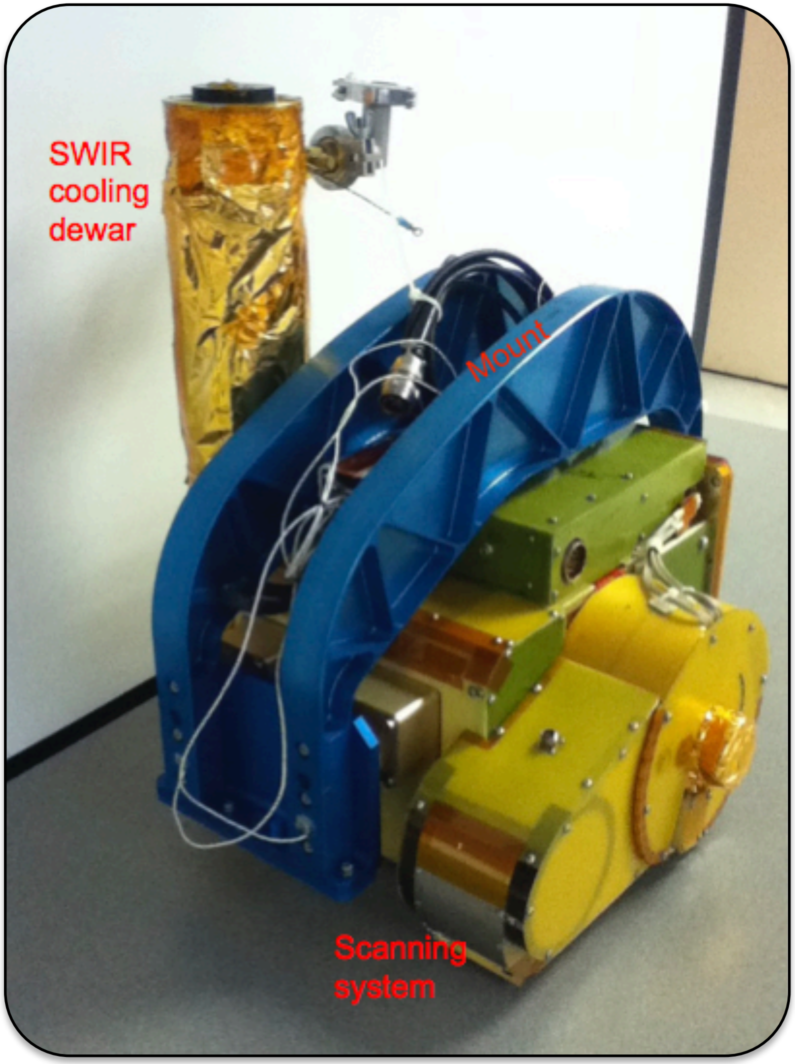
NAAMES
North Atlantic Aerosols and Marine Ecosystems Study

Mission Overview

- North Atlantic Marine Ecosystems Study (NAAMES)
  - 4 aircraft and ship measurement campaigns over 5 years
  - Each campaign is aligned to a specific annual event in the plankton cycle
  - November 2015 deployment had 5 science flights
- Goals
  - Characterize plankton ecosystem properties
  - Determine how marine aerosols and boundary layer clouds are influenced by plankton ecosystems in the North Atlantic

Research Scanning Polarimeter

- Prototype for Aerosol Polarimetry Sensor on the Glory satellite (2011)
- Along track scanning - 152 viewing angles per scene (±60°)
- 14 mrad field of view (~280 m on ground from 20 km alt.)
- Polarimetric and full intensity measurements in the visible and shortwave infrared over 9 bands: 410, 470, 555, 670, 864, 960, 1593, 1880, 2263 nm
- Measures aerosol: OT, R_{eff}, V_{eff}, refractive index, single-scattering albedo, morphology
- Measures cloud: OT, R_{eff}, V_{eff}, CTH, thermodynamic phase, ice asymmetry parameter, CDNC (?)



Measurements

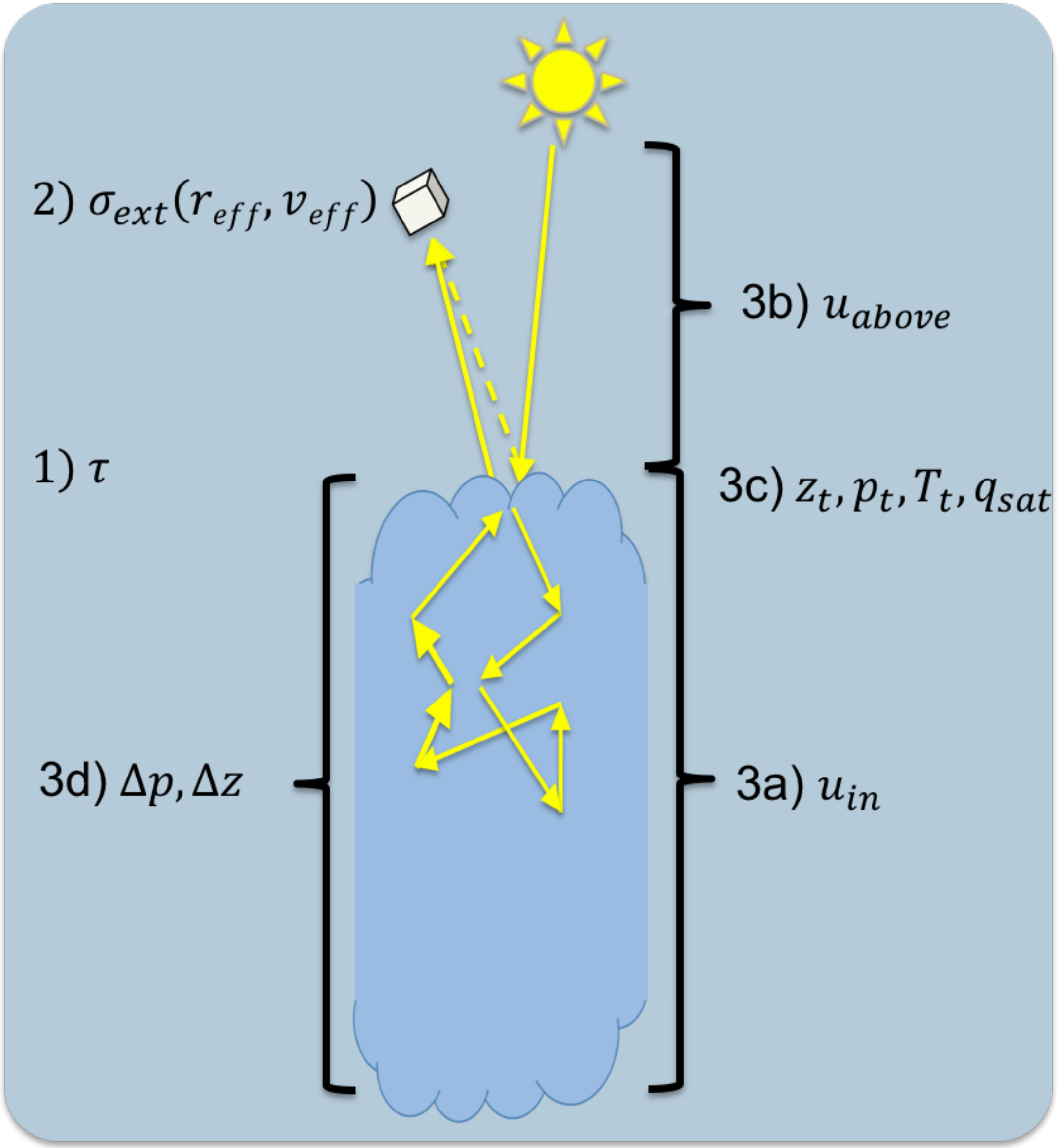
LARGE’s Cloud Droplet Probe (CDP-2)

- Forward-scattering optical spectrometer
  - Particle diameter (2-50 μm)
    - 30 size channels
  - Number concentration (0-2000 particles per cm^3) 20% accuracy
  - Liquid water content
  - Effective diameter
  - Volume median diameter
- Typical sample area: 0.24 mm^2
- Air speed range 10-250 m/sec

RSP CDNC Retrieval Method

$$N = \frac{\tau}{\sigma_{ext}\Delta z}$$

1) Cloud Optical Thickness, τ
2) Extinction cross-section, σ_{ext}
3) Cloud Physical Thickness, Δz



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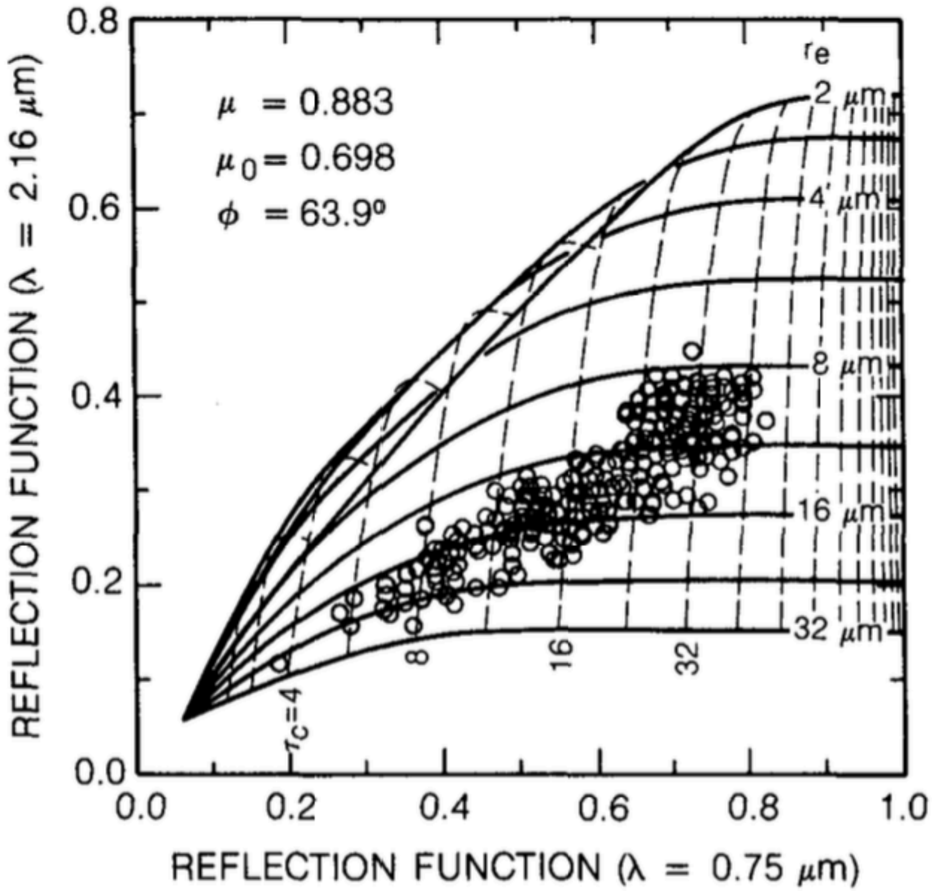
RSP CDNC Retrieval Method

$$N = \frac{\tau}{\sigma_{ext}\Delta z}$$

1) Cloud Optical Thickness (COT)
   - Use reflection function from 2 bands to determine cloud optical thickness
     - Non-absorbing 864 nm band
     - Absorbing 2263 nm band
   - COT is largely determined from reflection in the non-absorbing 864 nm band with some dependence on droplet radius



Nakajima & King (1990)

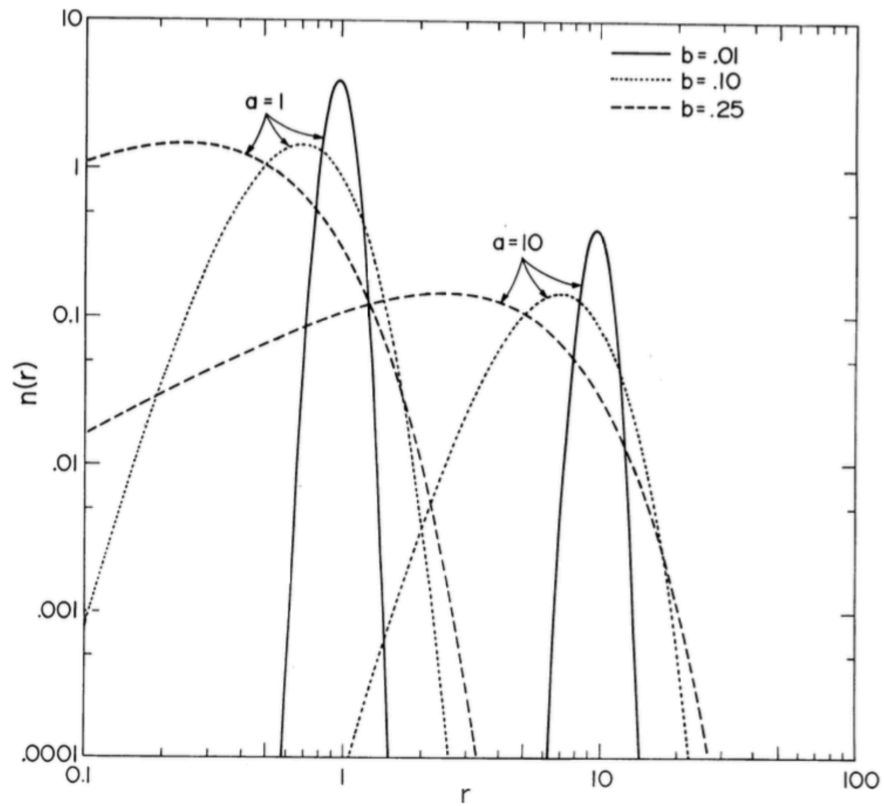
RSP CDNC Retrieval Method

$$N = \frac{\tau}{\sigma_{ext} \Delta z}$$

2) Extinction cross-section

$$\sigma_{ext} = \pi r^2 Q_e$$

- Extinction efficiency, Q_e
- Radii use a normal size distribution described by r_{eff} and v_{eff}
- 864 nm *polarized* band gives r_{eff} and v_{eff}



Hansen & Travis (1974)

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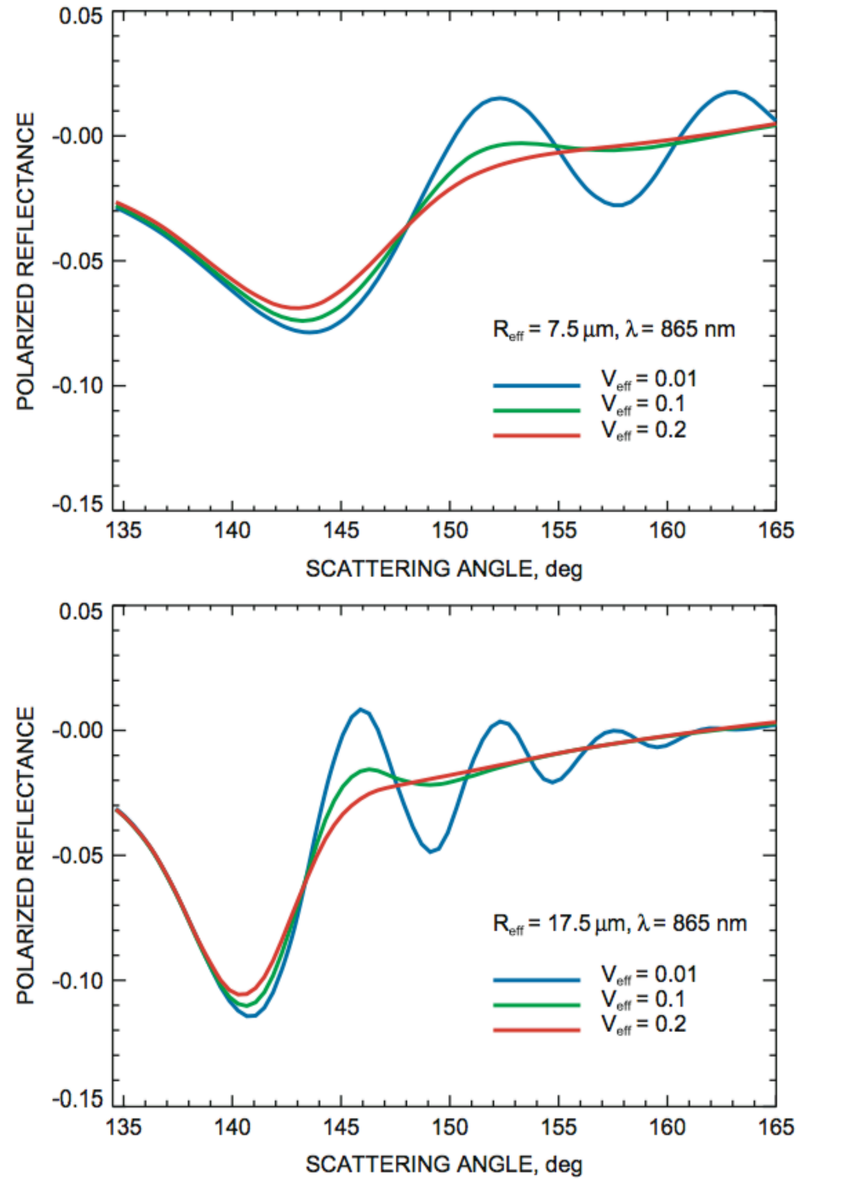
RSP CDNC Retrieval Method

RSP Size Distribution Retrieval

- Liquid clouds exhibit a strong rainbow feature originating from particles near cloud top
- The rainbow can be seen in polarized reflectances with scattering angles between 135° and 165°
- The shape of the rainbow is determined by single scattering properties of particles near cloud top, which correspond to a size distribution
- We fit a model to the observed rainbow observations to determine r_{eff} and v_{eff}



Alexandrov, Cairns, and Mishchenko (2012)

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RSP CDNC Retrieval Method

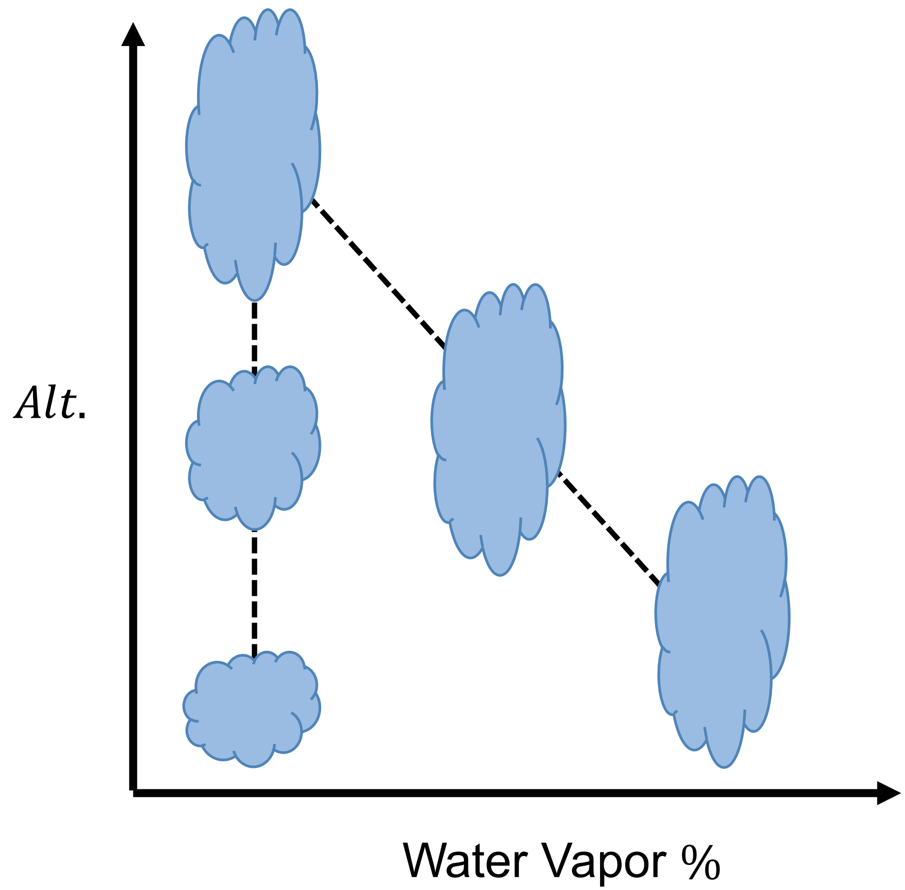
$$N = \frac{\tau}{\sigma_{ext}\Delta z}$$

3) Cloud Physical Thickness
   - *Key idea is to relate in-cloud water vapor absorption to cloud physical thickness ($u_{in} \sim \Delta z$)*

   a) In-cloud water vapor, u_{in}
      - Absorbing 960 nm & non-absorbing 864 nm bands

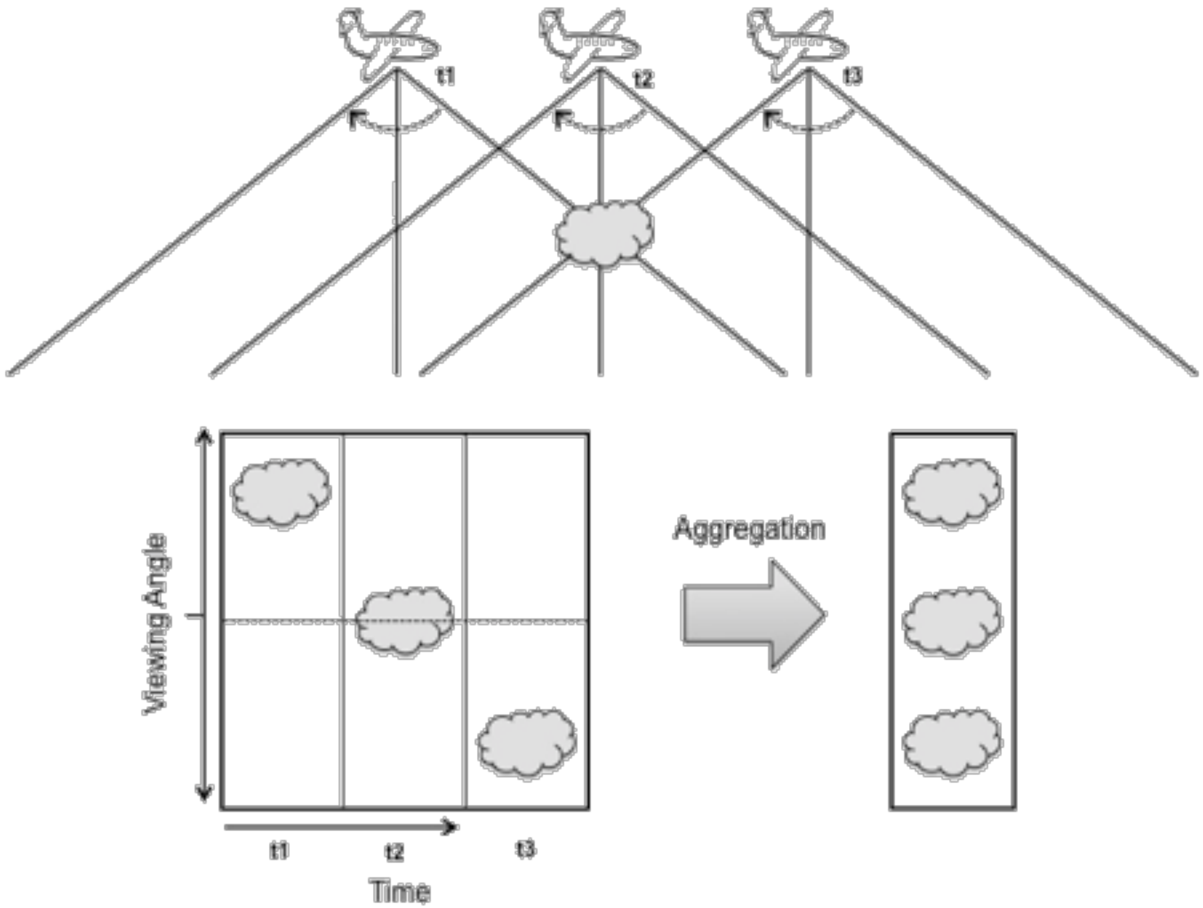
   b) Above-cloud water vapor, u_{above}
      - Absorbing 960 nm & non-absorbing 864 nm *polarized* bands

   c) Cloud top
      - 1880 nm band



RSP CDNC Retrieval Method

- We use a multi-angular contrast approach that uses the concept of *parallax*
- Distance from a stationary object is related to the displacement when observed from different viewing angles
- Similar to the photogrammetry used by MISR, but does not rely on identifying features
- Accurate knowledge of the geometry of the instrument and position of the aircraft is essential for stereo reconstruction



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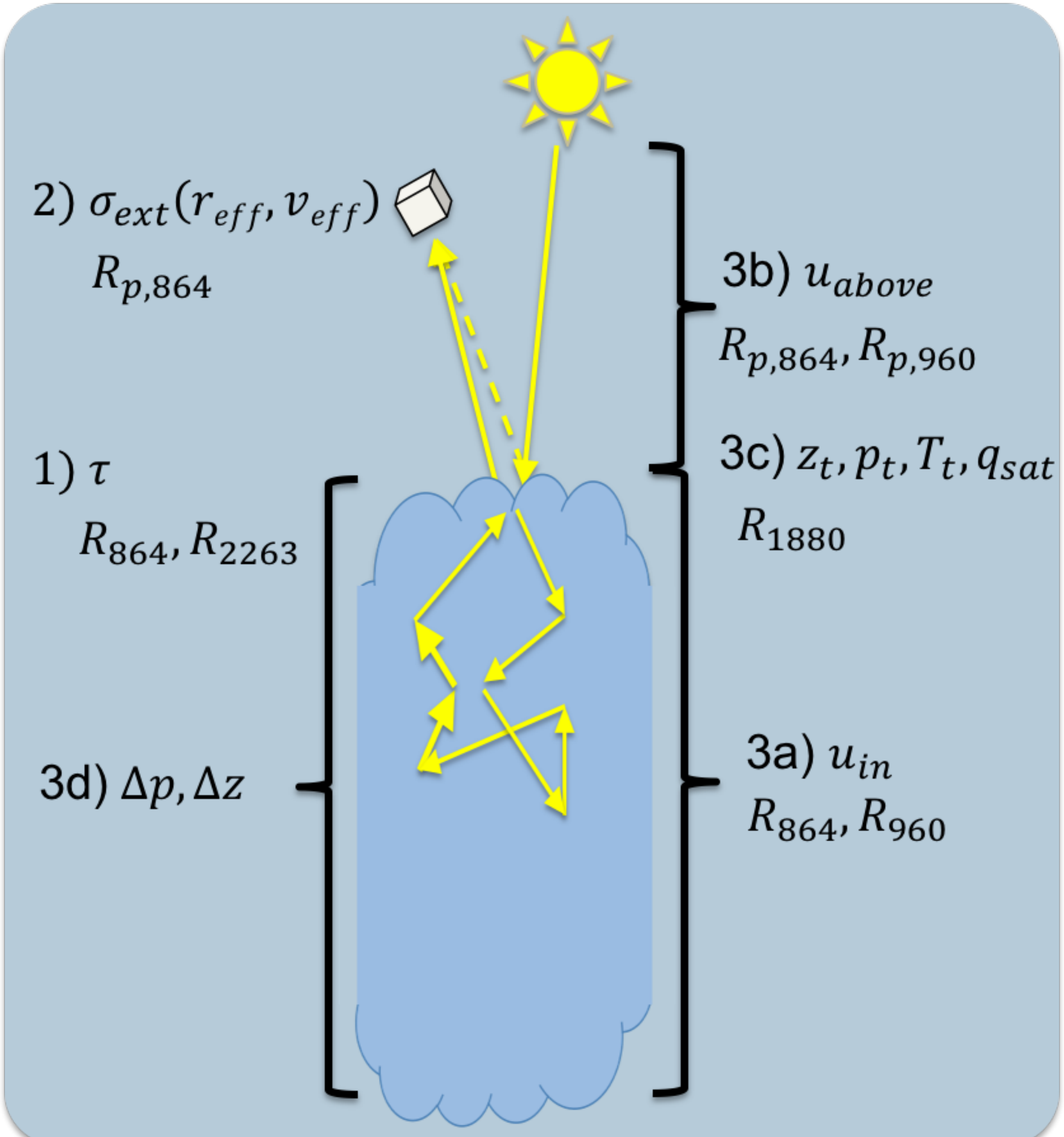
Alexandrov et al. (2012)

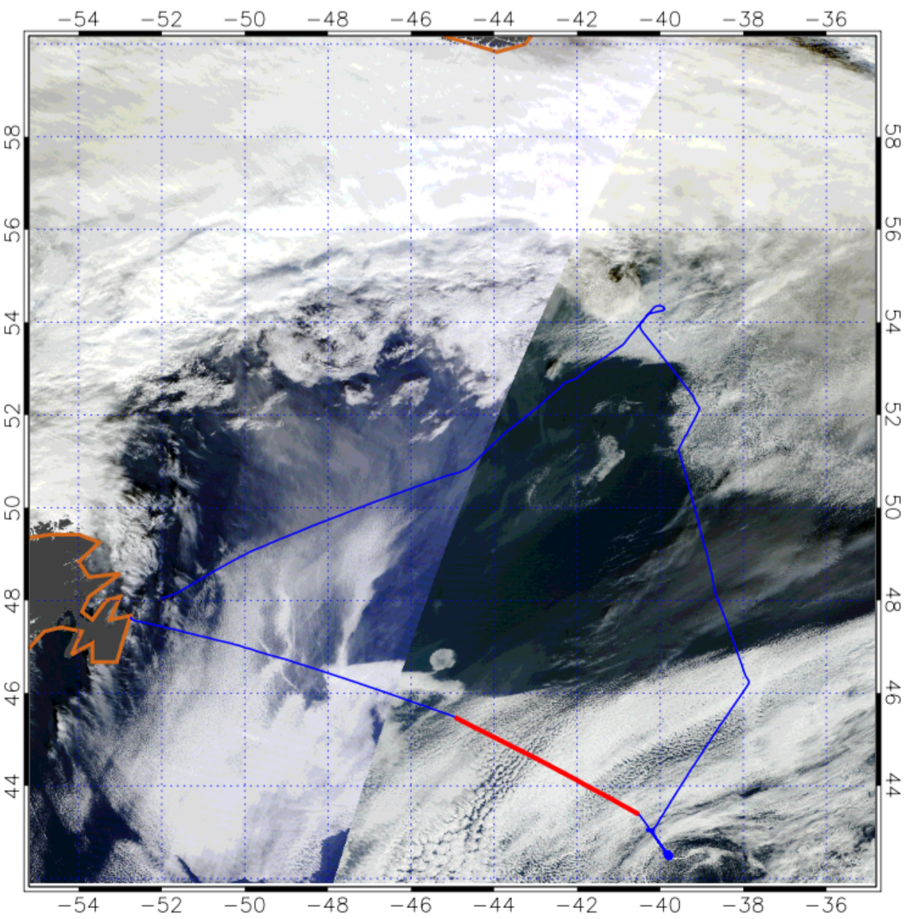
RSP CDNC Retrieval Method

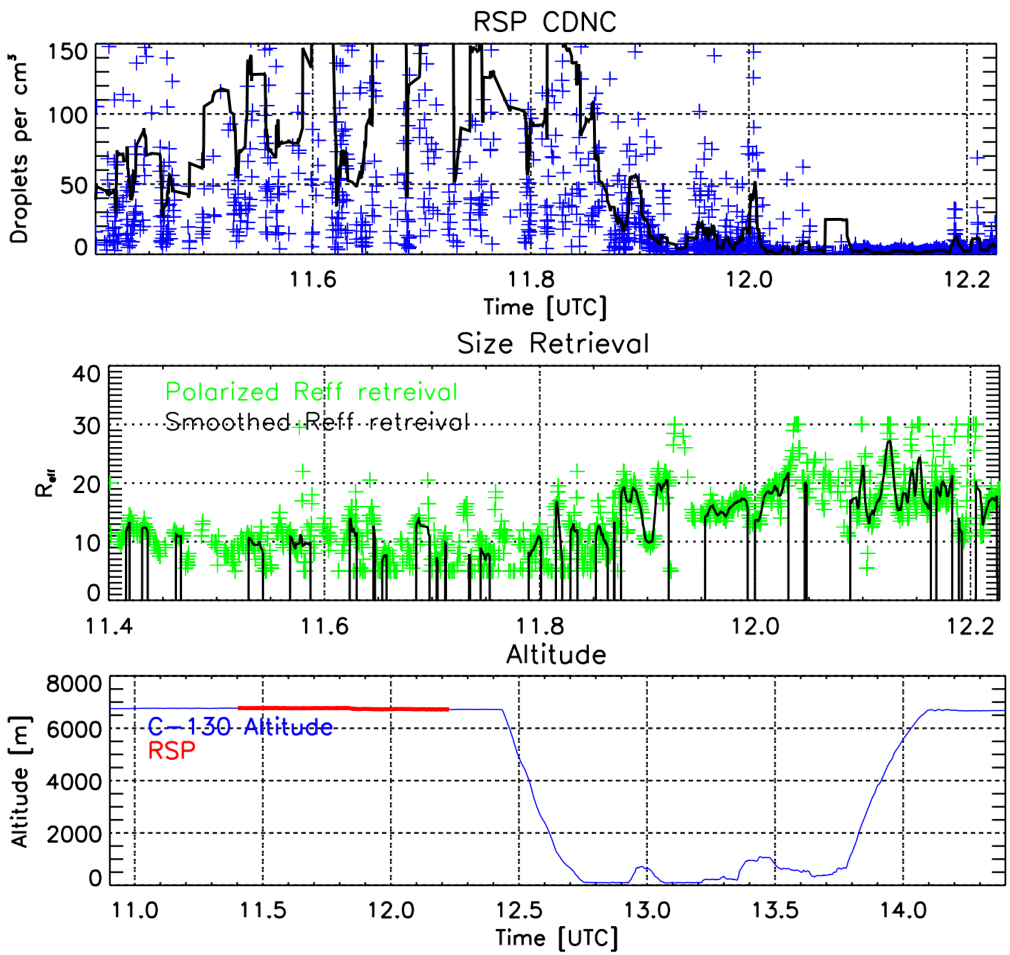
$$N = \frac{\tau}{\sigma_{ext}\Delta z}$$



Results

11/23/2015

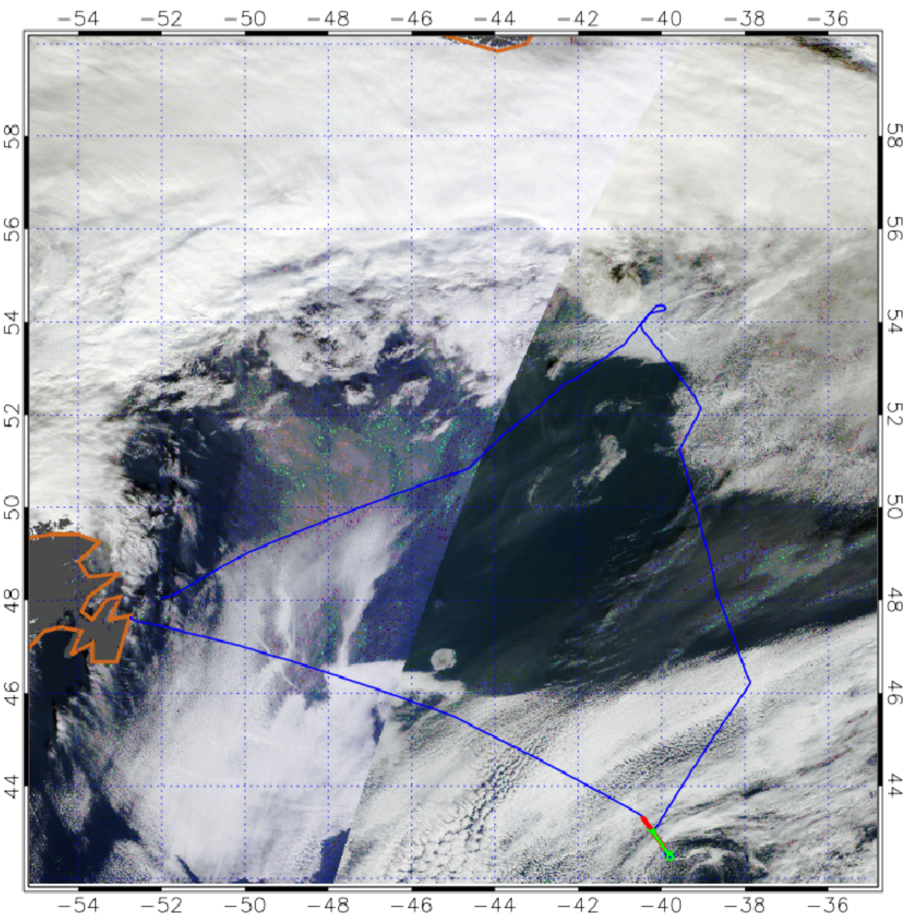


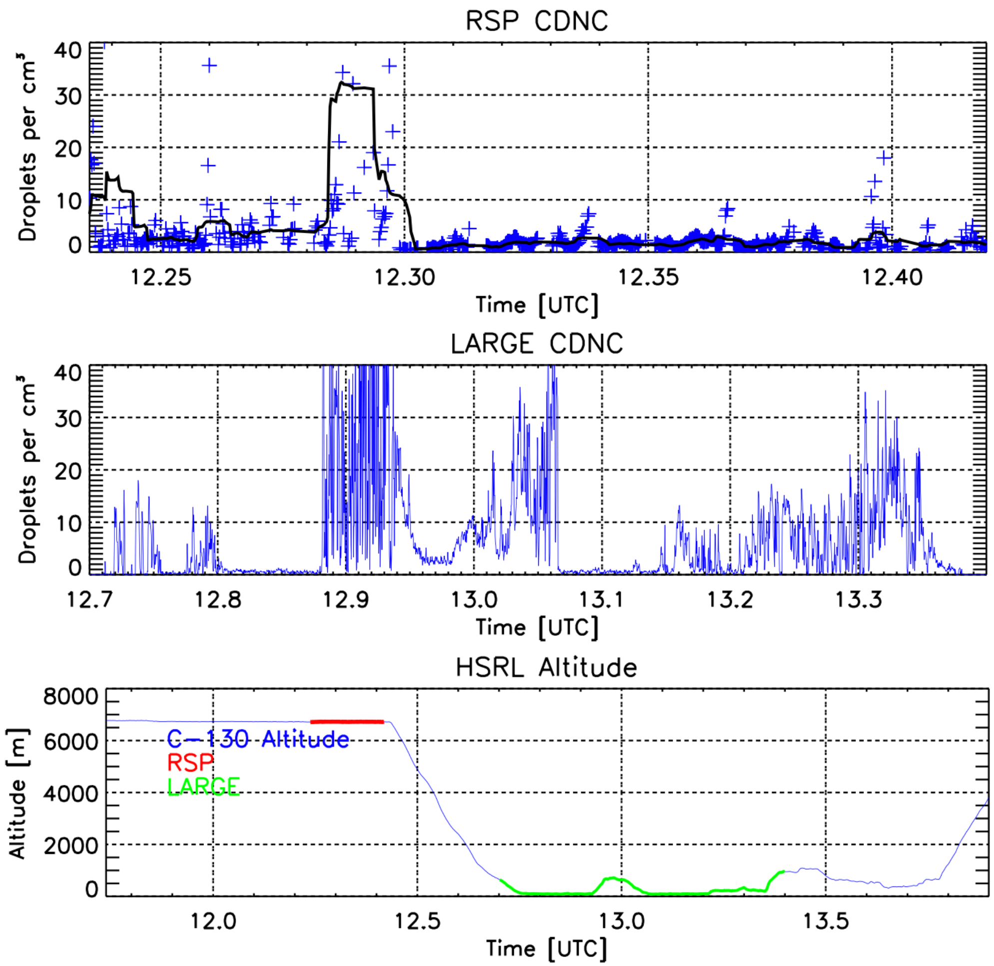


- Median 6 droplets per cm^3
- Mean 50 droplets per cm^3

Results

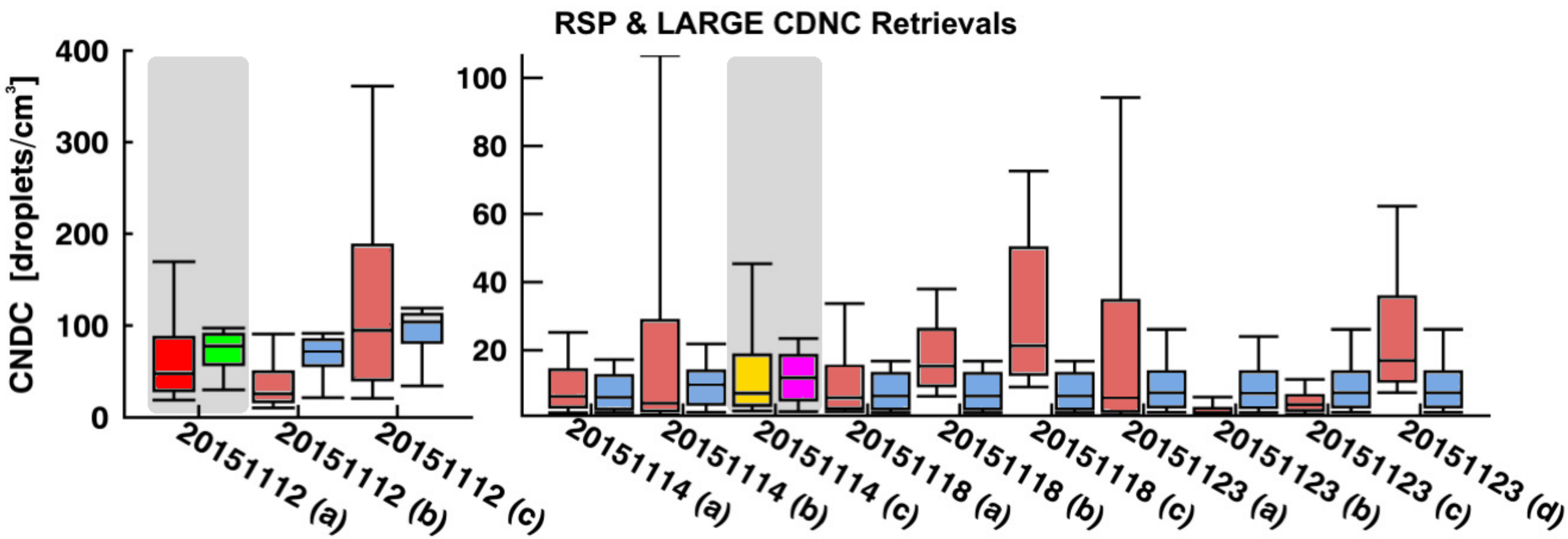
11/23/2015





- RSP median 2 droplets per cm^3 (n=561)
- LARGE median 7 droplets per cm^3 (n=1535)

Results



- Showing median and 10th, 25th, 75th, and 90th percentiles
- Collocation is done using relatively few LARGE samples
- November 12th saw elevated CNDC throughout the day
- Remaining 3 days saw low CNDC levels (<22 droplets/cm^3)

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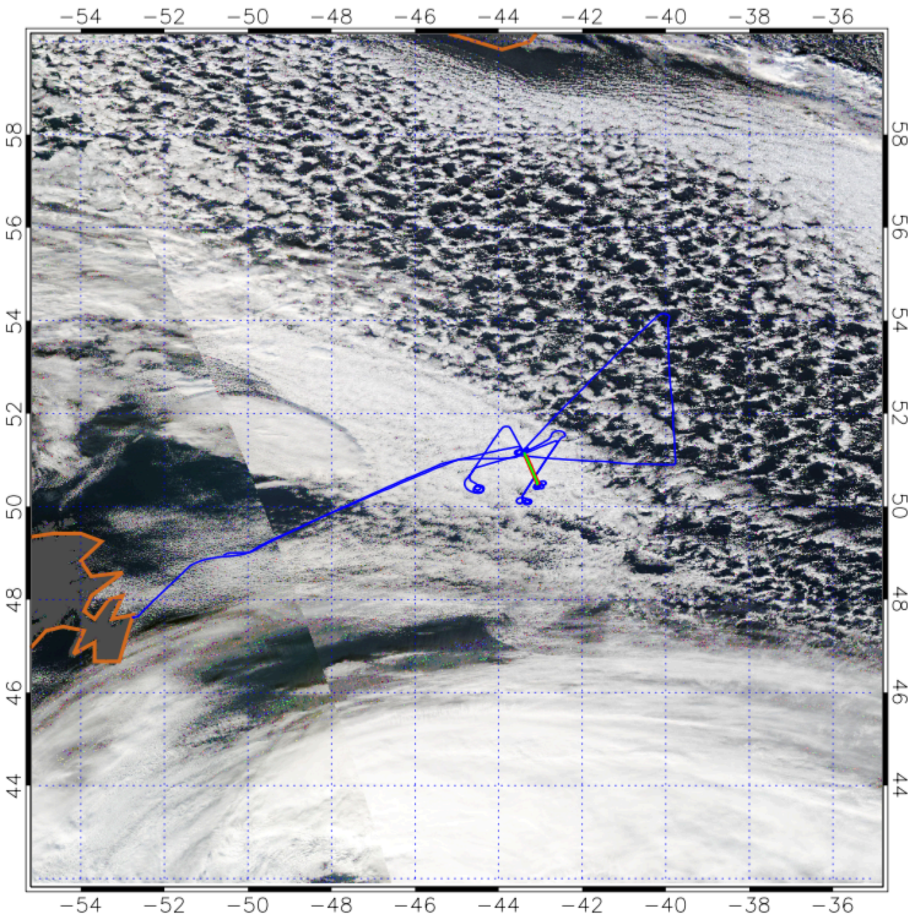
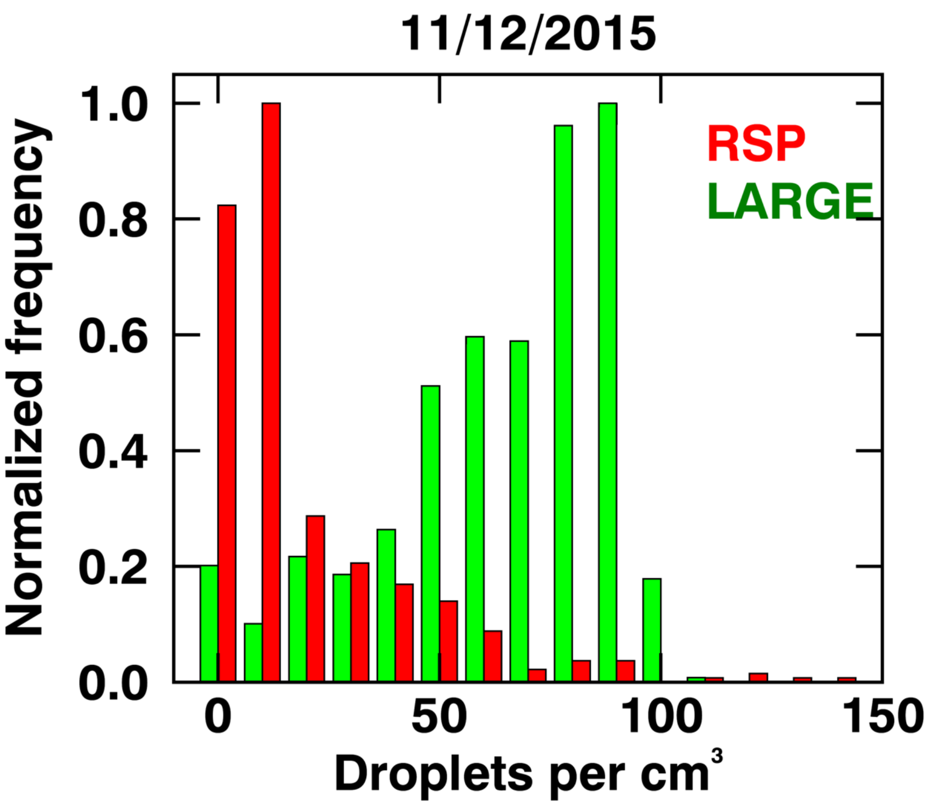
Results

11/12/2015





- RSP median 48 droplets per cm^3 (n=455)
- LARGE median 78droplets per cm^3(n=621)

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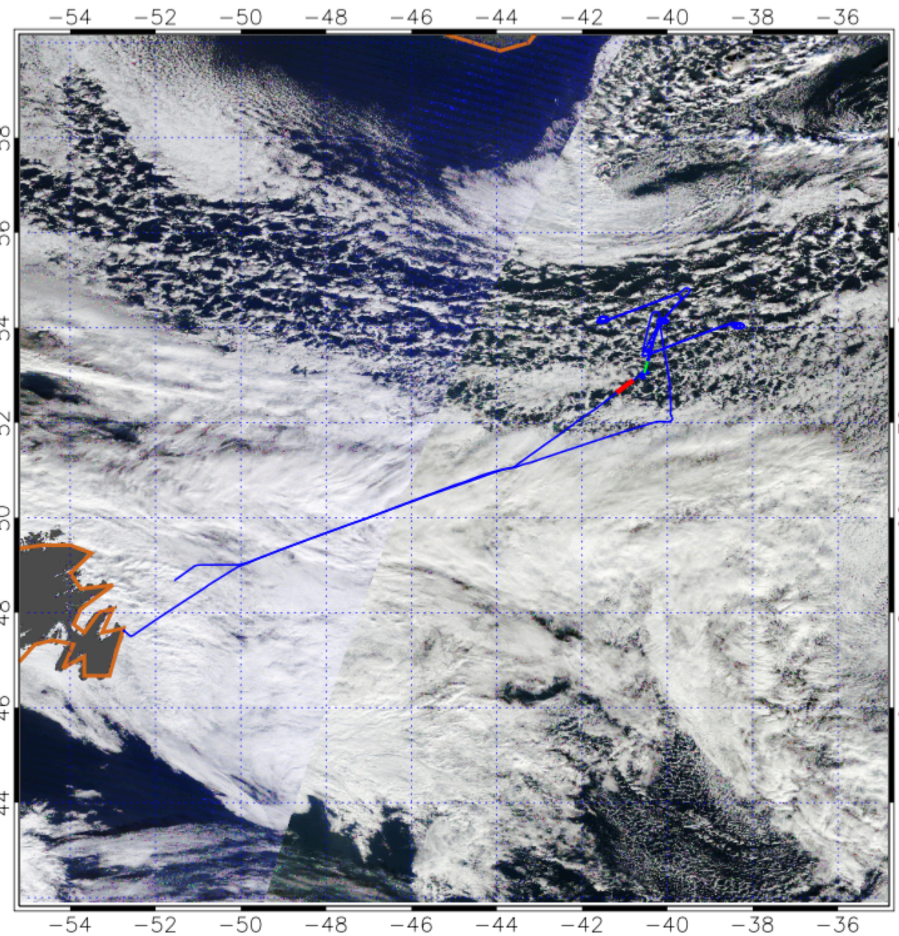
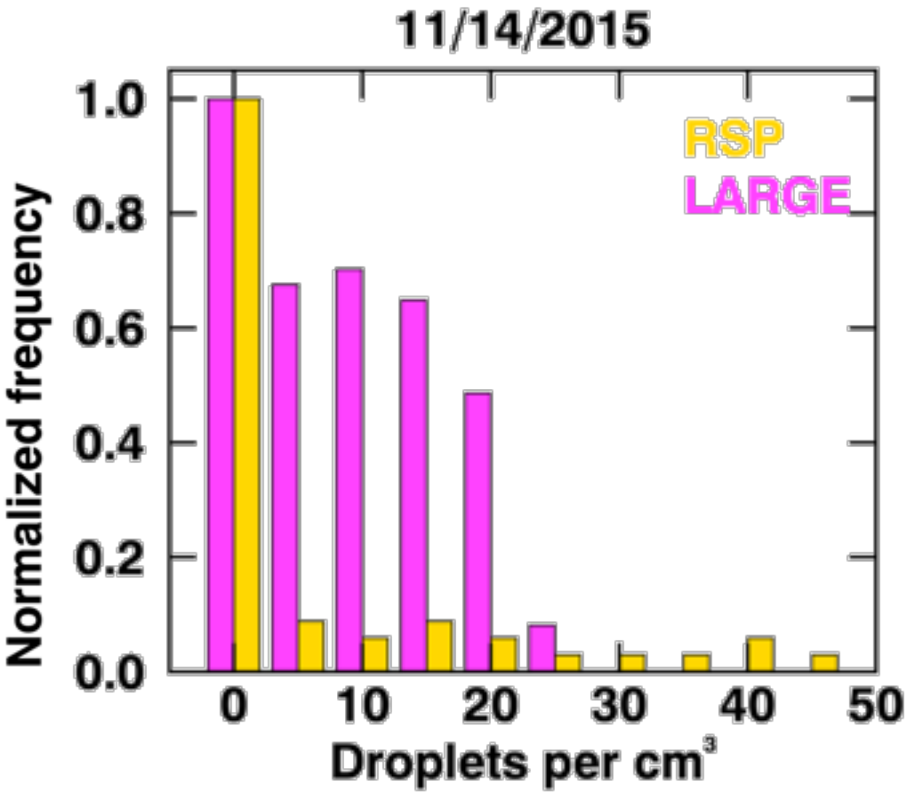
Results

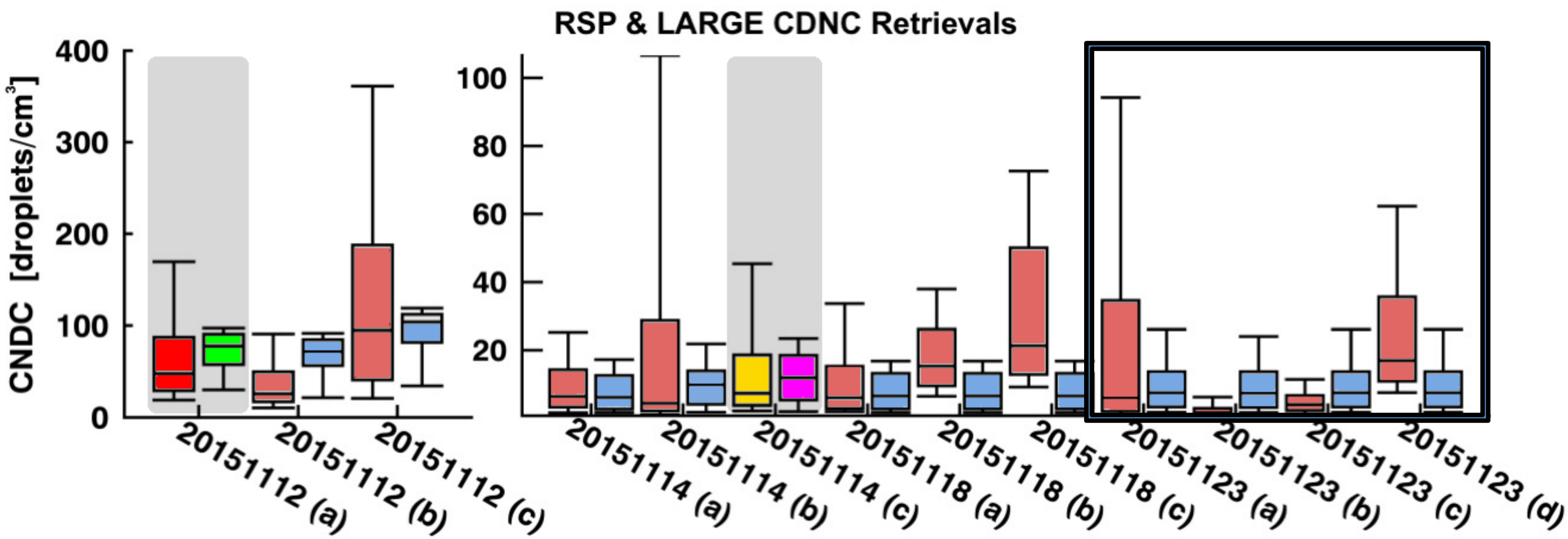
11/14/2015



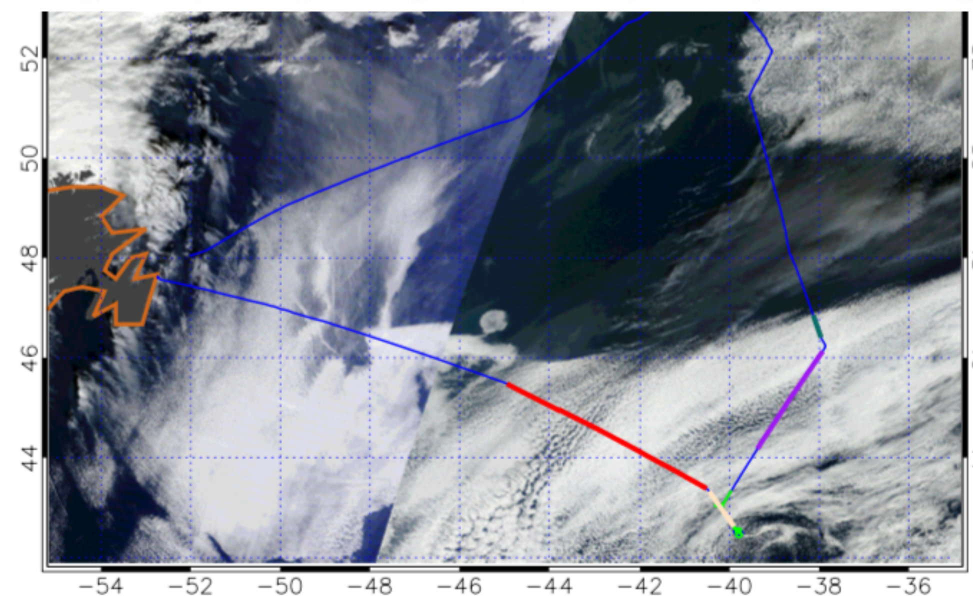


- RSP median 7 droplets per cm^3 (n=105)
- LARGE median 12 droplets per cm^3 (n=133)

Results



- High CDNC was measured for the first half of the 1st leg and the entire 4th leg
- Low CDNC for the 2nd and 3rd leg
- LARGE sampled near the low CDNC sections



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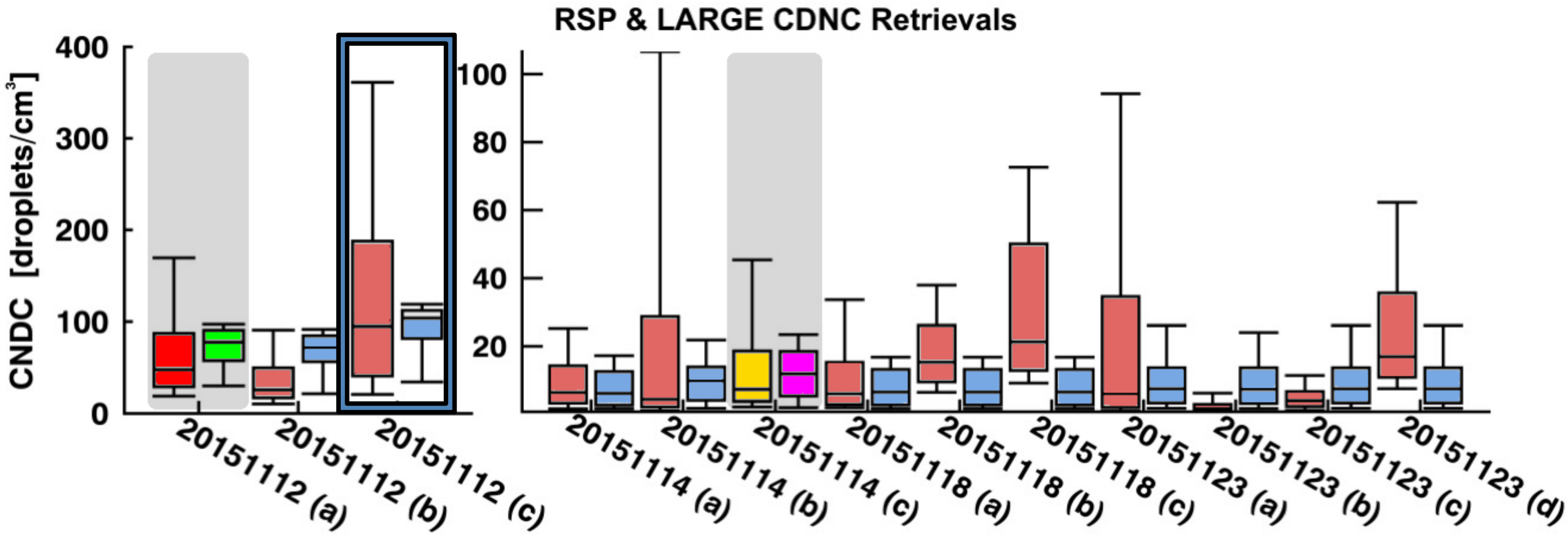
Results



- Good collocation
- RSP median 95 droplets per cm^3 (n=670)
- LARGE median 104 droplets per cm^3 (n=219)

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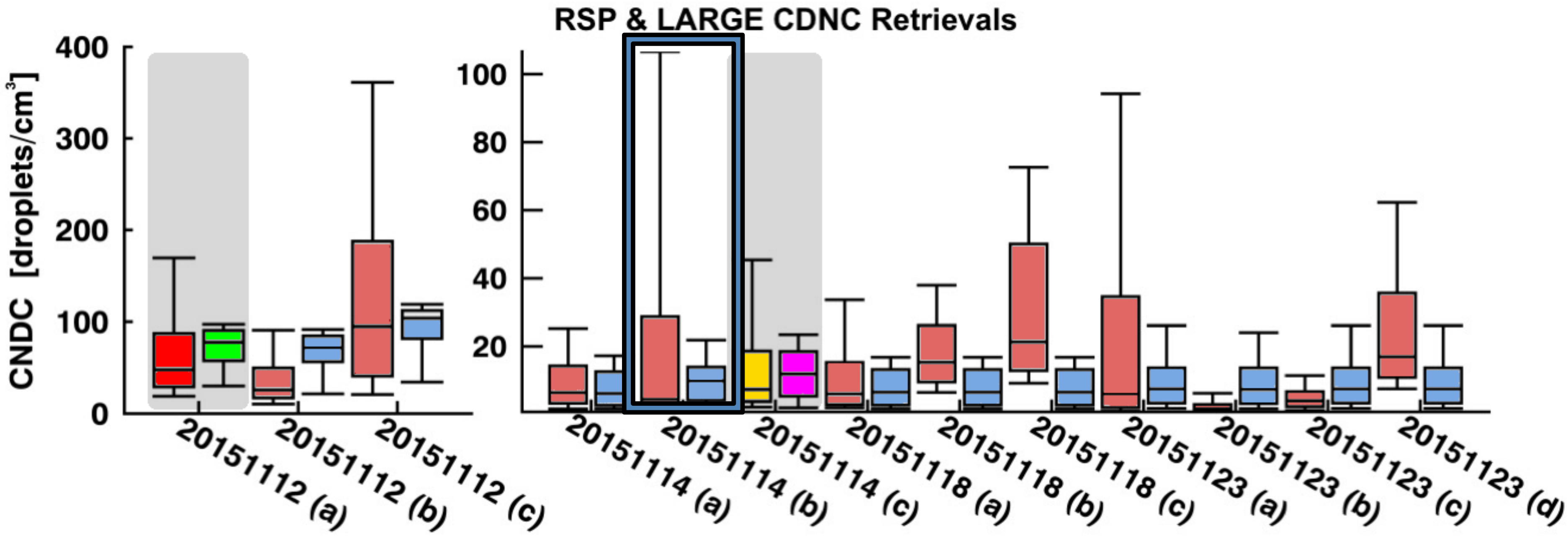
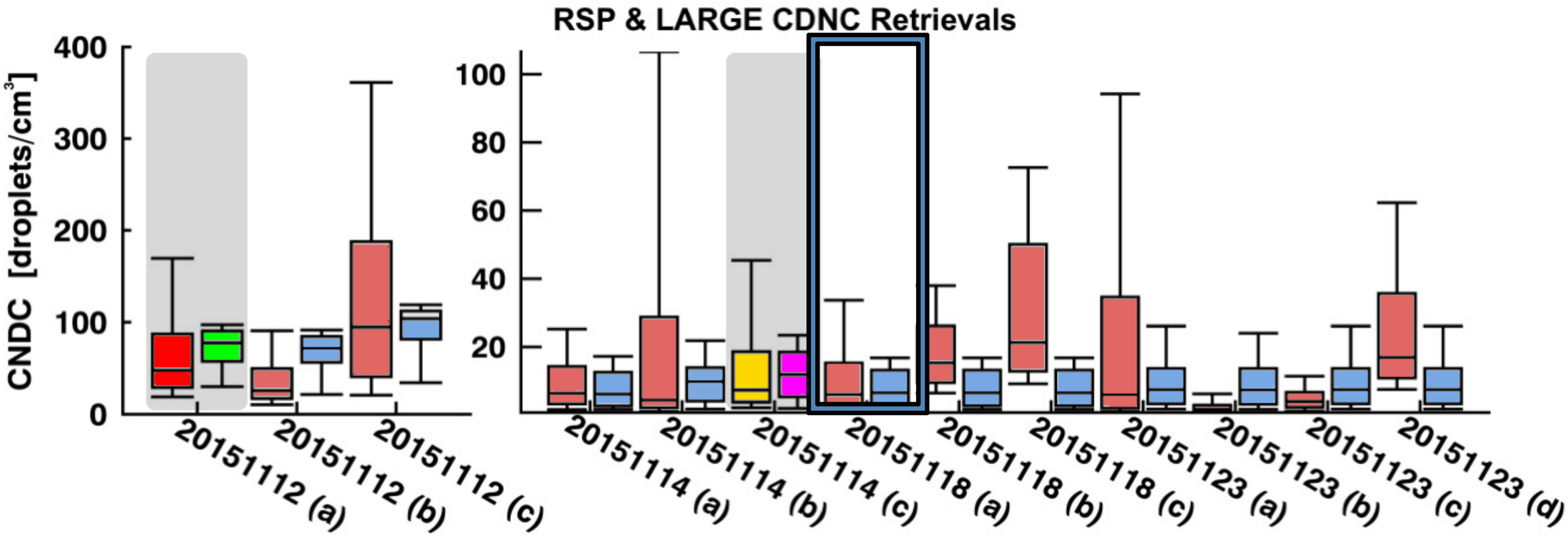
Results



- Parts of the flight leg had unrealistic cloud thickness

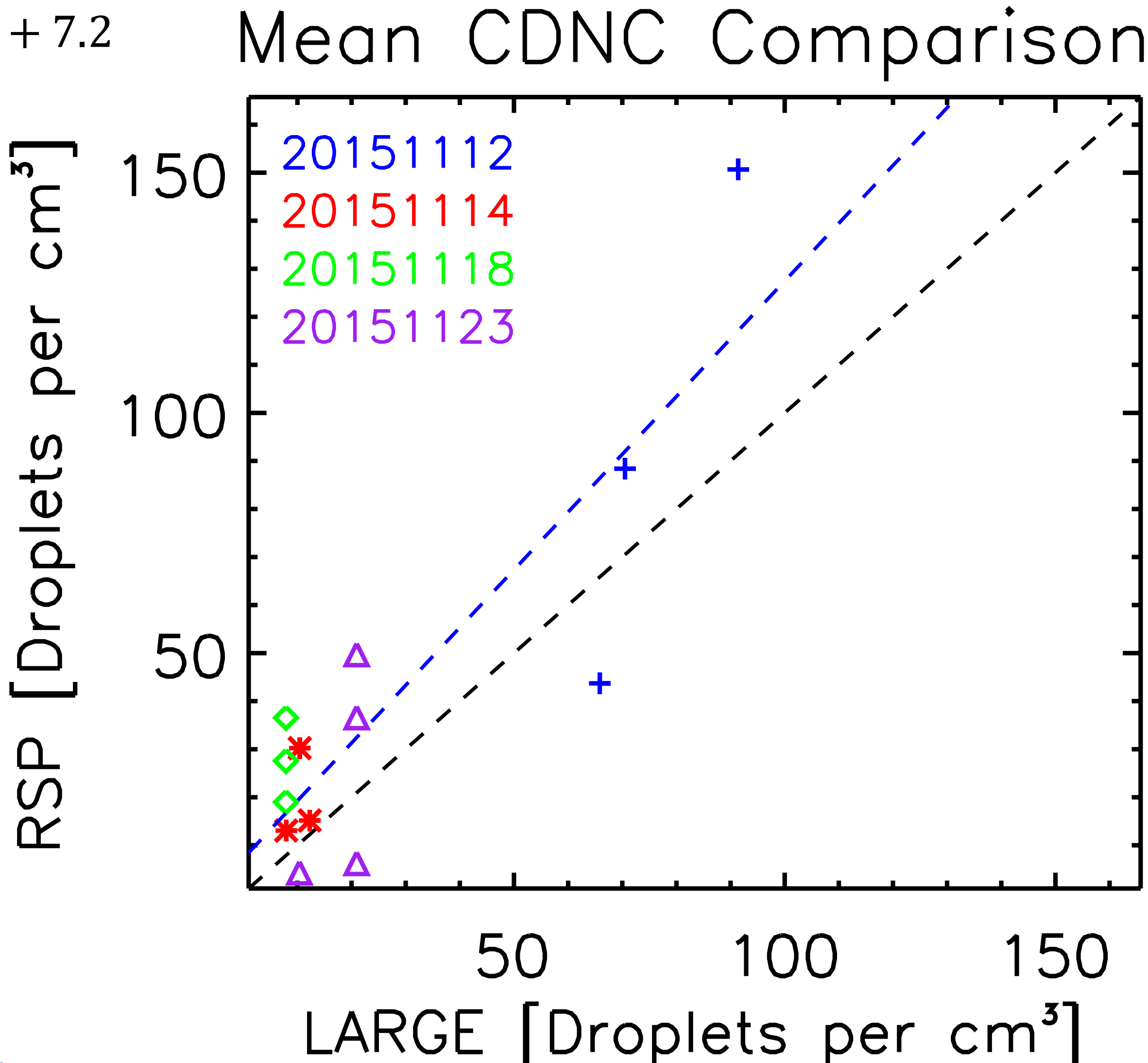
Results



- Many RSP retrievals (1013), but poor collocation

Results

$$N_{RSP} = 1.2N_{CDP} + 7.2$$



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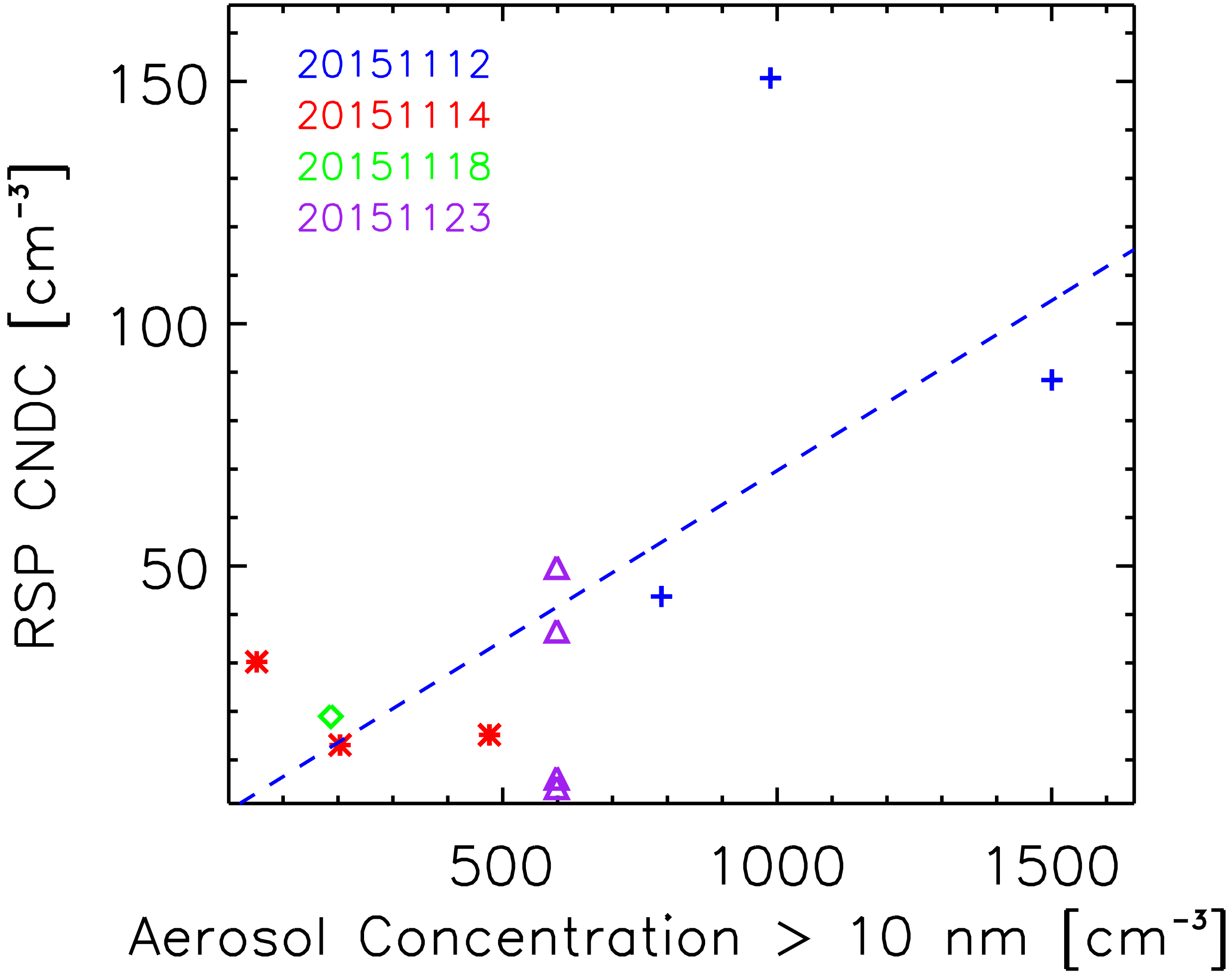
Results

Comparison with the Condensation Nucleus Counter

$$N_{RSP} = 0.07 \cdot N_{CNC} - 0.5$$



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Summary

1) Showed the basis for determining CDNC using the RSP
2) Demonstrated that the RSP can distinguish between various CDNCs
3) RSP results compared well to the LARGE CDP
4) Found a positive relationship between CDNC and aerosol concentrations

Future Work

- Next deployment: May 14th – June 4th
- HSRL retrieval & comparison
- Further relate RSP CDNC to aerosol concentrations

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